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DC POWER SUPPLY FOR
GASEOUS DISCHARGE LAMPS

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ABSTRACT

The design of a power supply to feed continuous-flow hydrogen lamps in vacuum UV photometric equipment is discussed. Following a general description, the electrical specifications, circuit description, and procedure for use and maintenance of such a power supply are given, together with a voltage chart and list of main parts. Finally, alternate embodiments of the power supply and features believed to be new are presented.

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DC POWER SUPPLY
FOR GASEOUS DISCHARGE LAMPS *

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1. GENERAL PURPOSE

This power supply has been designed to feed continuous-flow hydrogen lamps in vacuum UV photometric equipments. The anode of such lamps is the entrance pinhole of the optical system: therefore, the positive terminal of the power supply is grounded. The fact that the power supply provides a negative voltage with regard to ground does not prevent it from being used in connection with other lamps, such as low-pressure sealed lamps.

2. ADVANTAGES OVER PRIOR ART

It is easy to demonstrate that a gas lamp fed by a current source shows a much higher stability than if it were fed by a voltage source. The classic AC transformer for gas lamps is a good example of a current source. Its secondary electromotive force is ten to twenty times the lamp voltage and the secondary stray impedance, produced by a magnetic shunt, is very large compared to the lamp impedance. Thus, the current in the system is imposed by the transformer, and small variations of the lamp characteristics have a negligible effect. Some lamp manufacturers recommend a similar system

* US Patent Pending

for DC operation. For a 400 V lamp, a 1 kV to 2 kV power supply should be used, and the current limited by a large power resistor. This method for achieving a current source requires an expensive power supply, most of the power being wasted in the limiting resistor, but even so the stability remains insufficient for many applications. Another method consists in modifying a voltage-regulated power supply in order to have current regulation. The output voltage divider is replaced by a current-sensing resistor. Unfortunately, these power supplies have been originally designed to have a very low output resistance, and for this reason, the load is normally in the cathode circuit of the regulator tube. Such a system would work perfectly on a quiet resistive load. But on a gas lamp which produces large transients when impurities are "burning", the low transient output resistance of the power supply will often lead to unstable operation.

A power supply manufacturer was requested to design and build a current source for gas lamps. We were met with a well-understandable reluctance motivated by the poor commercial interest and high cost of such an instrument.

Therefore, we started to design and build these power supplies, using only readily available commercial components. All these current sources have been extensively tested, simplified and improved, and we believe that they will fulfill all the requirements of most experimenters.

In our design, the regulator tubes are used as current sources. The load is in the anode circuit and a resistor is introduced in the cathode circuit to serve both as a feedback resistor and also as a current-sensing resistor. The error-signal amplifier produces a very strong feedback which makes possible the use of an internal resistance as high as 500 kilohms at DC and still 40 kilohms at 40 kHz.

We solved the problem of very large transients (400 V peak/0.1 microsecond rise time) produced by impurities or foreign gases by introducing a filter, mounted at the end of the coaxial lamp cable, as close as possible to the lamp. As "seen" by the lamp, this filter appears as a 40 kilohm resistor with a stray capacitance of less than 100 pF at frequencies above 20 kHz.

The filter, using an air choke, will limit the current variations during voltage transients as high as 600 V peak, thus increasing the lifetime of the lamp.

3. GENERAL DESCRIPTION

The power supply is a current source with an output resistance several orders of magnitude higher than the dynamic and static resistance of the lamp from DC to the high frequency region. The recovery time is short, and the regulation very smooth, without overshoot, in order to prevent the extinction of the lamp during transients. The stray capacitance in parallel with the lamp has been kept as small as possible to prevent the lamp from operating as a relaxation oscillator.

The current can be adjusted between 10 mA and 110 mA with a precision 10-turn potentiometer. The current can be read directly on the dial. A 10 ohms precision shunt allows the user to monitor the current with an external instrument such as a voltmeter or DVM. The terminals of the shunt are brought to two test points on the front panel. The negative side of the shunt is grounded.

When the IGNITION push-button is depressed, a 2 kV - 60 Hz half-wave is applied to the lamp to assure a proper ignition. The state of the lamp (ON or OFF) is displayed by an indicator on the power supply control panel.

A passive L-R-C RF filter mounted as close as possible to the lamp, at the end of the coax-cable connecting the lamp to the power supply, prevents the noise generated by the lamp from disturbing the power supply. Furthermore, this filter limits very efficiently the current flowing through the lamp when arcs are produced by the combustion of impurities or foreign gases on the electrodes, thus reducing the amount of metallic vapors projected into the optical system.

4. ELECTRICAL SPECIFICATION

Current range:	10 - 110 mA DC adjustment by 10-turn potentiometer
Output voltage range:	see load diagram (Figure 1)
Ignition voltage:	2 kV
mA - meter:	external. Use a 0 - 1.1 V DC voltmeter connected across the 10 ohms precision shunt. (R_i voltmeter \geq 1000 ohms/volt)
Output resistance:	0.5 Megohms at DC 40 kilohms at 40 kHz
With additional filter:	40 kilohms/50 pF
Line regulation (117 V \pm 10%):	\pm 0.2%
Temperature coefficient:	0.01%/°C
Ripple:	50 μ A p-p
Current accuracy (dial):	\pm 0.1 mA from 20 to 100 mA
Stability (12 hours):	\pm 0.05 mA

5. CIRCUIT DESCRIPTION

The power supply is divided into four subsystems: the rectifiers, the ignition circuit, the regulator, and the external filter.

5.1 THE RECTIFIERS

The high-voltage rectifier is floating (Figure 2). Its positive end is connected to the anode of the regulator tubes. Its negative end is connected to the cathode of the lamp. The load characteristic of the rectifier is:

Lamp current	Rectifier voltage output
0 mA	810 V
10 mA	720 V
30 mA	645 V
100 mA	595 V

The only reason for using two transformers (TR1-TR2) for this power supply is that these transformers were readily available from stock at GSFC. A custom-made 700 V transformer would have required a longer delivery time. Since the rectifier is floating, it is of prime importance to have, on the average, no AC voltage across the stray capacitance between the secondaries of the transformer and the ground.

If the two-transformer system is used, the two primaries must be connected in opposition of phase, and the other low-voltage windings grounded on one side or at their center tap. If the more elegant solution of a custom-made transformer is desired, it is recommended that the H.V. secondary be wound in sandwich between two grounded electro-static shields. In the first case, we found a stray 60 Hz current less than 50 microamps. It is highly recommended to filter the negative and the positive side in order to reduce the transients caused by the stray inductance of the transformers during the commutation of the diodes. R1 and R2 balance the DC voltage across C2 and C4.

The current in these resistors should be at least 5 times the leakage current of the capacitors.

TR3 with its associated rectifier and filter provides an overall voltage of 100 V. This feeds the solid-state amplifier through a chain of Zener diodes giving voltages of -6.3 V, +20 V and +50 V.

5.2 THE IGNITION CIRCUIT

When the ignition push-button is depressed, a negative half-wave 1550 V (rms) 60 Hz voltage is applied to the lamp. As soon as the lamp

ignites, the diode switch D9-11 is held open by the normal lamp current. The ignition voltage is short-circuited and the ignition current is limited by resistor R15. During normal operation, the current flowing through R15 is negligible (approximately 40 μ A).

5.3 THE REGULATOR

As can be seen from Figure 3, the current from the + end of the floating rectifier flows through the five regulator tubes connected in parallel, the load balance resistors R20-R24, the Zener diodes DZ12 - DZ16 and DZ9 (Bias) and through the current-sensing resistors R16 and R17. R16 is a precision 10 ohms shunt used for accurate current measurement. The current from the ground passes through the lamp, the external filter, and returns to the rectifier. The Zener voltage divider (R4, D12, DZ7) which is temperature-compensated, gives a stable reference voltage (7.00 V).

The potentiometer P3 adjusts the ratio of the highest output current to the lowest output current ($110 \text{ mA}/10 \text{ mA} = 11/1$). In other words, $R_P1 = 10 \times (R_6 + RP3)$. P2 adjusts the range, which is exactly 10.0 mA output current variation for 1.00 turn of P1.

The dial of P1 is adjusted for an accurate reading of the current using the 10 ohms precision shunt and a digital voltmeter (e.g. 50.0 mA for 5.00 turns).

The differential amplifier T1, T2, T4 amplifies the current error signal and T3 drives the regulator tubes. The amplifier T3 with its filter C8, C9, R33 has the following frequency response:

Frequency	Response	Output resistance
0 - 80 Hz	Flat	500 kilohms
80 - 800 Hz	-6db/Octave	-----
0.8 - 40 kHz	Flat	50 kilohms
Above 40 kHz	-6db/Octave	-----

The output resistance of the power supply appears in the third column.

The "Lamp ON" pilot lamp is triggered by the voltage across R18. As soon as the current through R18 reaches 7 mA, the relay RL turns the pilot lamp on. The voltage across R18 is limited at 33 V by DZ9. DZ17, in parallel with the current-sensing resistors, protects the differential amplifier against large transients.

5.4 THE EXTERNAL FILTER

The main part of this filter is a 300 mH air inductor made from an 8 henry - 40 mA filter choke whose iron core had been completely removed. R101, in conjunction with the capacitance of the output coaxial cable of the power supply, filters the front wave of the transients by-passing the choke through its stray capacitance.

6. USING THE POWER SUPPLY

Before using the power supply, check that the desired lamp current and lamp voltage fall within the area of permissible operation of the load diagram.

Connect the external filter to the lamp, the red lead (+) to ground or to the anode, the black lead (-) to the cathode. Then connect the input of the filter to the output of the power supply. Adjust the dial at the desired current and turn the power on. If the lamp does not start, depress the "IGNITION" push-button. If the lamp still does not start, increase the pressure of the lamp (1 to 10 mm Hg for H₂).

The pressure in the lamp must be high enough to assure a stable burning. Intermittent operation, flickering, and impossibility to restart the lamp when it is hot are the symptoms of too low a pressure, or excessive power applied to the lamp, or insufficient cooling of the cathode.

At very low pressure, continuous-flow lamps sometimes show a negative resistance due to unstable pressure distribution within the lamp. It is recommended to connect an oscilloscope to the lamp when looking for the optimum pressure for the lamp. *Warning:* the ignition voltage may damage the oscilloscope. Unstable pressure distribution in the lamp will appear as high-frequency oscillations on the scope. Under normal operation, noise and ripple together should not exceed 0.5 V peak-to-peak.

A strong magnet, located after the exit pinhole of the lamp will deflect ions generated within the lamp and accelerated by the electric field. The magnetic field will prevent these ions from reaching sensitive optical components such as gratings or mirrors. Of course, the magnetic field must be perpendicular to the optical axis of the lamp.

7. MAINTENANCE

The only components subject to aging are the regulator tubes and the electrolytic capacitors of the rectifiers. They should be replaced after 2000 hours of operation. The following voltage chart indicates the voltages at different points of the power supply for a 7500 ohm resistive load, without external filter, and an output current of 40 mA.

7.1 VOLTAGE CHART

Voltage W.R.T. ground, 20 kilohm/V instrument.

Load: 7500 ohms Current: 40 mA

Main Rectifier: 620 VDC overall

Ripple after 1st choke 1.7 V pp (60 + 120 Hz)

Ripple after 2nd choke 0.4 V pp (60 Hz)

Output (Load) -300 V

Ripple 0.4 V (60 Hz)

Low Voltage Rectifier

100 V DC overall

Tubes

V_a	+320 V
V_g	+28
V_k	+43

Amplifier

V_{CC3}	+50 V
V_{CC1}	+20 V
V_{BB}	-6.3 V
V_{ref}	+7.00 V
$V_{B1} - V_{B2}$	+1.6 V
V_{C1}	+7.9 V
V_{C2}	+12 V
V_{E3}	+2.2 V
V_{C3}	+28 V
V_{C4}	+1.0 V
V_{E4}	-1.7 V
V_{B4}	-1 V

7.2 MAIN PARTS LIST

<u>Component</u>	<u>Type</u>	<u>Manufacturer</u>
D1 to D11	1N561	TI
DZ	1N753 63 V 0.4 W 1N758 10 V 0.4 W 1N2990 33 V 10 W	TI TI TI

L1 to L4	8 H, 140 ohms, 140 mA	
L5 to L6	8 H, 450 ohms, 40 mA	
P1	1 kilohm, 10 turns	Beckman
P2	Trimpot, 200 ohms, 15 turns	Bourns
P3	Trimpot, 20 ohms, 15 turns	Bourns
R5 & R6	Hi. Stab. Metal Film 0.25 W	
R15	10 Megohms, 3 kV, 2 W	RPC
R16 & R17	WW 10 ohms, 1%, 0.5 W low TC	
R30 to R32	50 Megohms 1 kV	RPC
T1, T2, T4	2N930	TI
T3	2N1613	RCA
TR1 & TR2	PSC 105 2 × 345 V, 105 mA	Chicago Std. Transf. Co
TR3	Isolation tr. 1:1 40 W	
TR4	P-8150	Stancor
V1 to V5	6S4	RCA

8. ALTERNATE EMBODIMENTS

The first alternate embodiment presented here has already been built and tested at GSFC. It is a simplified version, intended to replace the AC transformer for low-pressure mercury lamps (Pen-Ray) when the 120 Hz modulation of the light source is a major inconvenience, for instance in star-tracker testing. Furthermore, an audio modulation of the light source can be easily performed by this power supply. A 2.5 V peak-to-peak audio signal can be applied to the grid of the regulator tube through an 0.1 microfarad coupling

capacitor. The linearity of the modulation is good over a 200 Hz to 5 kHz range. A 1-megohm resistor may be connected between the cathode and the anode of the regulator tube, preventing the lamp from being turned off by excessive modulation.

If a higher output current is desired, a similar power supply may be designed using the same block-diagram, and more powerful regulator tubes and rectifier. It might be interesting to take advantage of the large variety of power tetrodes and pentodes available on the market and, in the future, of high-voltage semi-conductor devices. Their high amplification factor and high plate resistance make them very suitable for use as current sources. However, it must be noticed that the screen current must not be allowed to return to the cathodes through the current-sensing resistor; thus, the screens should be biased by a separate floating power supply whose positive end would be connected to the screens of the regulator tubes and the negative end to the cathodes of these tubes. In this way, the screen current will flow in a closed loop from the screens to the cathodes and back to the rectifier without interfering with the regulated anode current.

In order to reduce the plate dissipation of the regulator tubes, they should be operated at the lowest possible plate voltage. This could be done by using steps on the H.V. secondary of the power transformer. Six or seven 50 V steps would give a sufficient adjustment capability. The plate voltage might be displayed on the front panel. The step transformer would be adjusted in such a manner that the plate voltage would stay between 200 and 300 V.

9. FEATURES BELIEVED TO BE NEW

As far as we know, the ignition system is new. It does not require a thyratron or a high-voltage relay. The diode switch connects the lamp, once it is ionized, to the main rectifier without current break and without voltage or current transients.

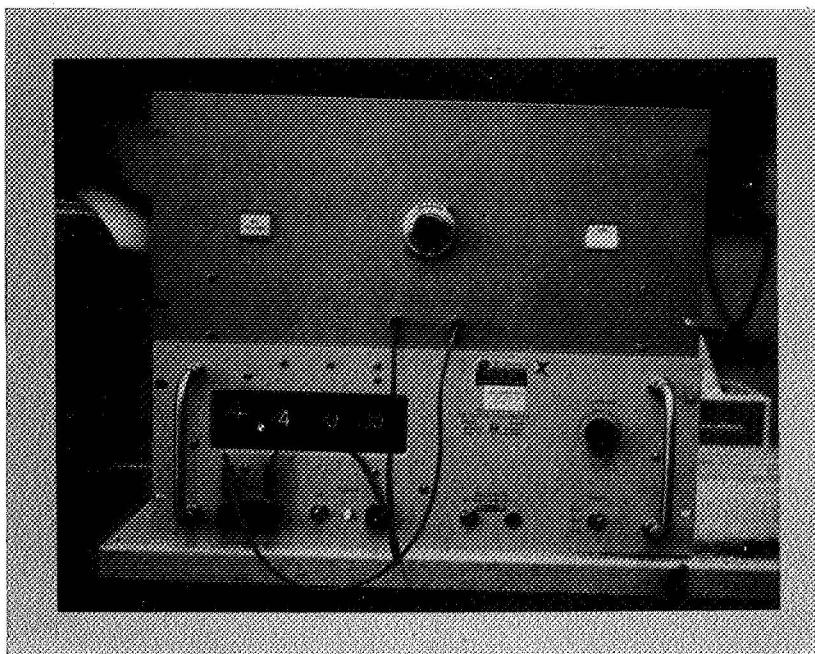
The external filter mounted in the immediate vicinity of the lamp is also believed to be new. Its ability to stop large transients makes the power supply an almost ideal current source up to the high frequency region.

Otherwise, there is nothing new in the circuit design of these power supplies. It is a classic schematic diagram of a current source. The innovation is that this method, with adequate adaptations, has been successfully used to feed gaseous discharge lamps, especially continuous-flow lamps, requiring an unusual negative voltage with regard to ground.

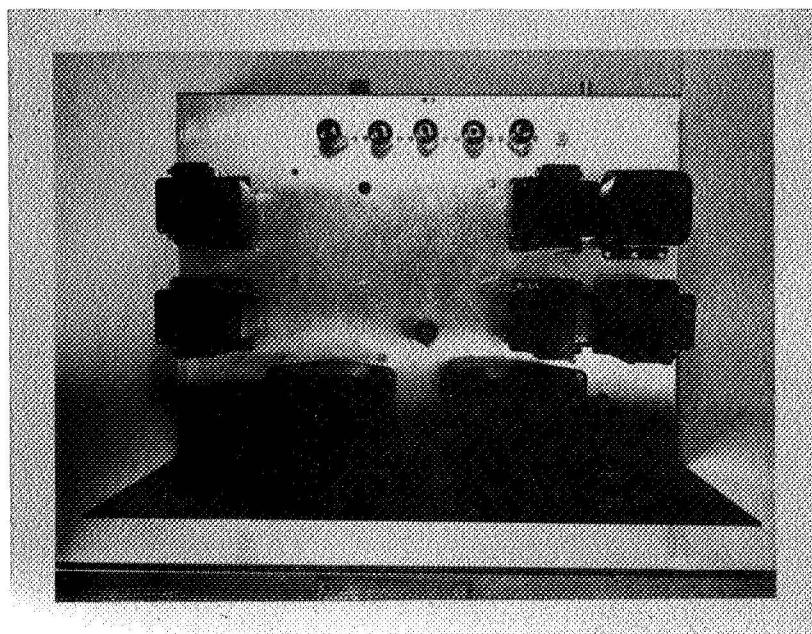
10. CONTRIBUTION OF EACH INVENTOR

The general design and the modifications of this power supply have been worked out in a joint effort. The detail circuit design and the tests have been made by D. Huguenin. The mechanical design and the construction of the prototype have been made by W. Freeman.

Plate I

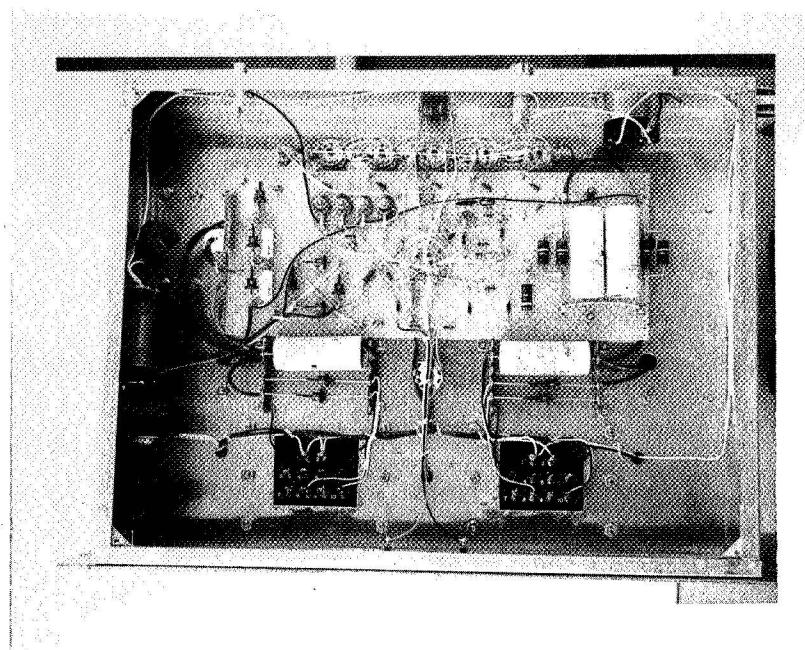


a) Front view of power supply showing digital voltmeter for accurate reading of the current.

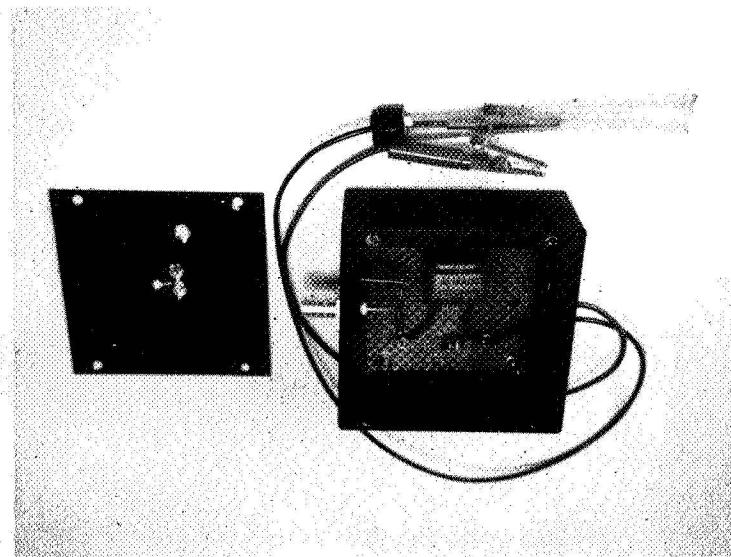


b) Top view.

Plate II

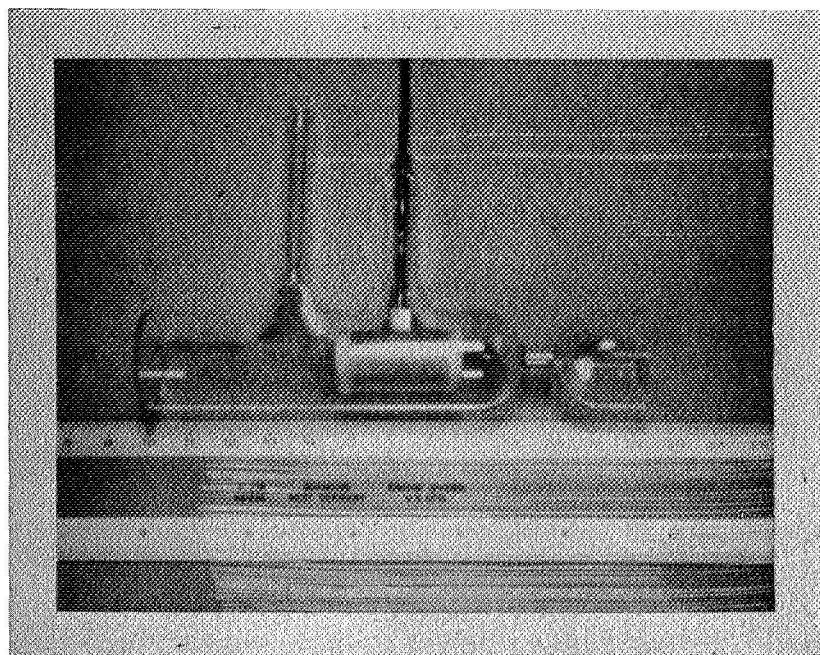


a) Bottom view.

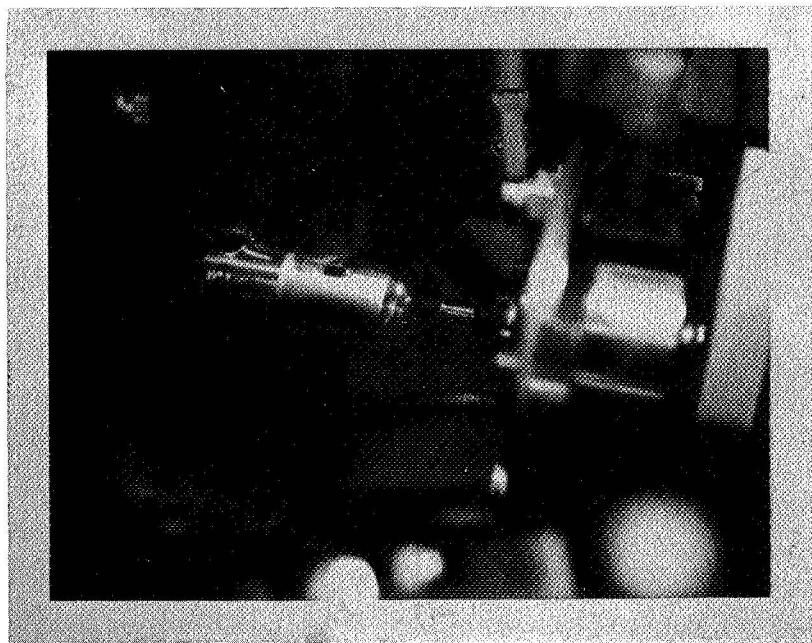


b) External filter.

Plate III



a) Continuous-flow H_2 lamp.



b) The lamp mounted on a vacuum monochromator.

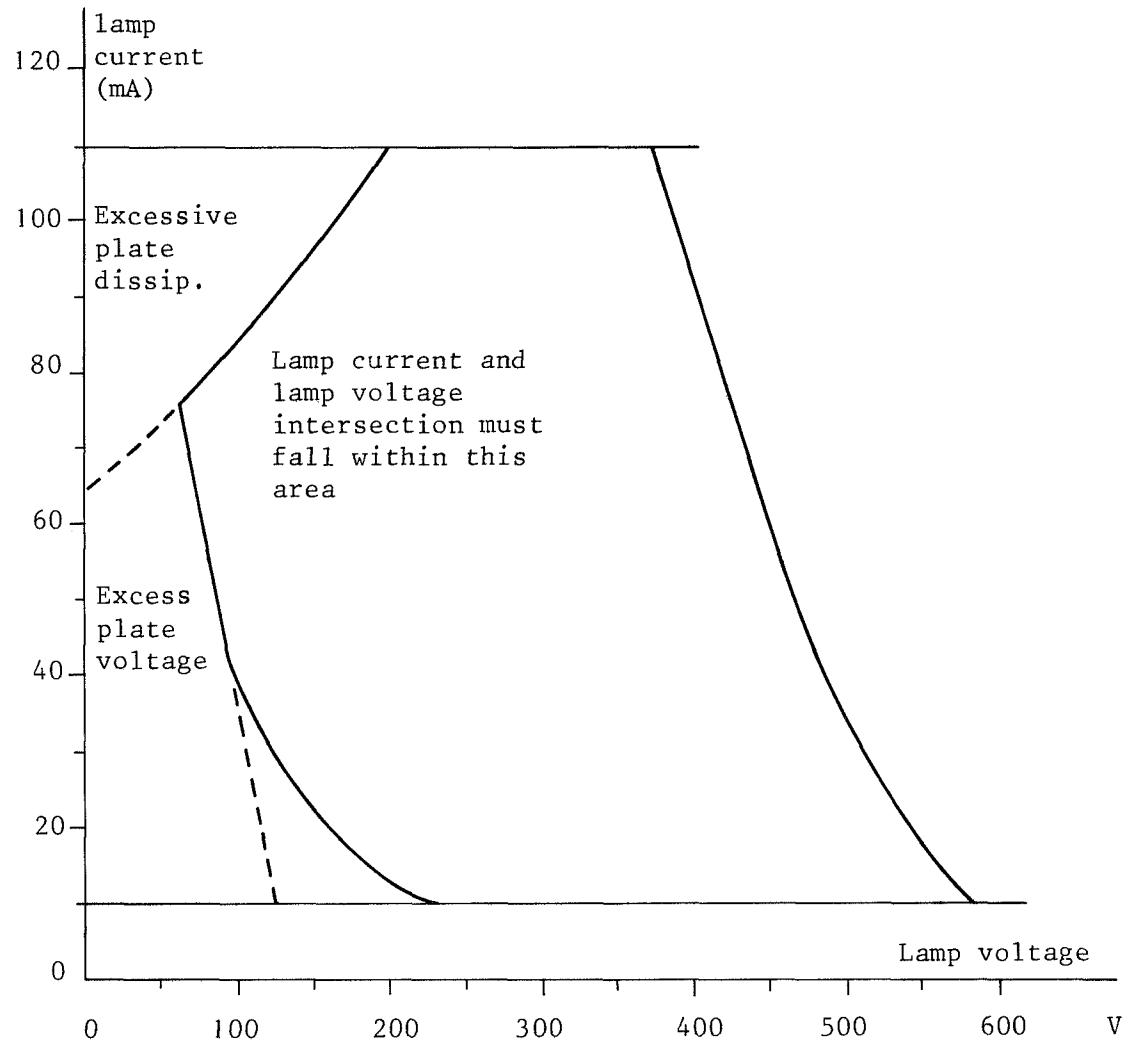


Figure 1.- Load diagram.

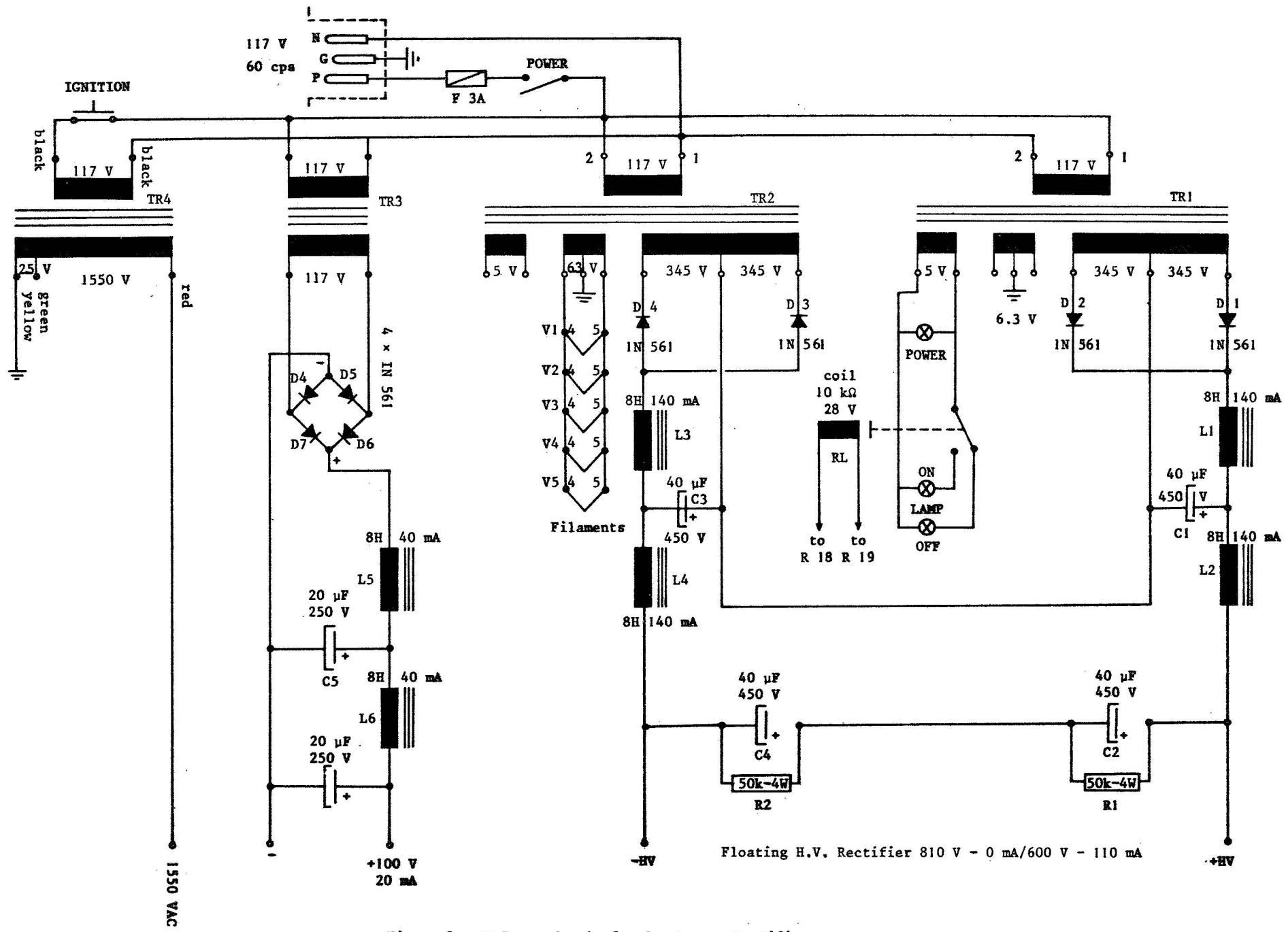


Figure 2.- DC Power Supply for Gas Lamps: Rectifiers.

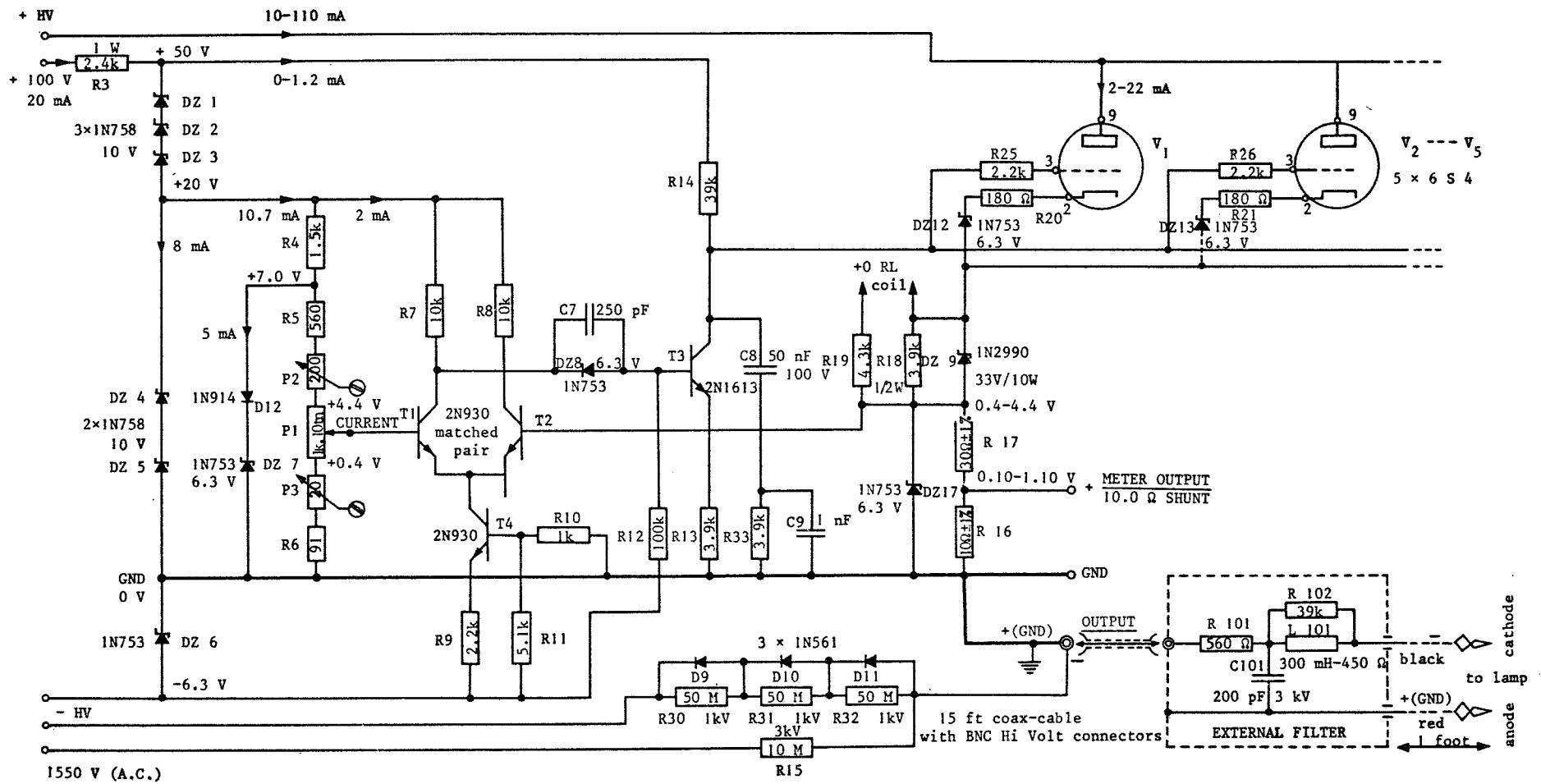


Figure 3.- DC Power Supply for Gas Lamps: Regulator and Filter.